Written Contributions to the EHR Advisory Committee Social Sciences Workshop

Convened February 22, 1996
at the National Science Foundation
Arlington, VA

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Convened February 22,1997

Listed alphabetically. Titles indicate the speakers' positions at the time of the Workshop.

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Contributions of the Social Sciences to the National Science Foundation Review of Undergraduate Education

Overview

On February 22, 1996, a group of eight invited scholars from the social and behavioral sciences met to discuss the improvement of undergraduate education. Joining them were members of the Advisory Committee for Education and Human Resources at NSF, the Assistant NSF Director for Education etc. (Luther S. Williams), the Assistant NSF Director for Social and Behavioral Sciences (Cora Marrett), representatives from several education and policy associations in Washington DC, and NSF professional staff concerned about undergraduate education. Over 50 people participated in this workshop during the course of the day. The discussions were joined by most that were present at the workshop.

The workshop was designed as part of the extensive review of undergraduate education being conducted by a Subcommittee of the Advisory Committee for Education and Human Resources, which began the previous spring. This review is examining the status, conditions, and needs of undergraduate education in the broad disciplines of the sciences, mathematics, engineering and technology.

The invited participants were asked to prepare short statements prior to the workshop in response to a set of questions that focused on the contributions of the social and behavioral sciences to improving our understanding of how to improve undergraduate education. The questions were:

- What has social and behavioral science research contributed to our understanding of how students learn?
- What are the obstacles to implementing change in curriculum and instruction in undergraduate education? How do we overcome them?
- What are the unanswered questions about student learning that research needs to address?
- How does knowledge of the social sciences and of technology prepare students for the next century?

The following is a summary of the key points made during the workshop. The comments can be organized around four major themes: the undergraduate learner, the teacher, the curriculum, and the institutional context. To maintain a sense of authenticity, direct quotes from participants have been included in a number of places.

The Undergraduate Learner

How the student learns, as well as individual and group characteristics of the learners, are important factors to be considered. At the beginning of the workshop, participants agreed to a basic principle: the mind is active. Research in cognitive psychology indicates that “the mind always interprets,” and is not simply “a passive receiver of information that is broadcast to it” (Rochel Gelman, Department of Psychology, New York University). Thus, the presentation of new and interesting information in the classroom is not enough; we must also understand how the minds of students interpret and manipulate that information.

The processing of information by students is a vital point of concern. Students rarely realize the applicability of information and knowledge from one context to another, and often view information as facts to be memorized and mechanically reproduced in an exam. In a rapidly changing world, a more desirable outcome would be for students to possess the ability to apply abstract principles to different situations, e.g. to "recognize situations in their own environments where the Law of Large Numbers applies" (Neil Stillings, School of Communication and Cognitive Science, Hampshire College, Amherst, Massachusetts).

Undergraduate students come from diverse communities and cultures with distinctive expectations about the education process. The values, norms, and expectations of students about what to expect from undergraduate studies in their chosen institutions of higher education are influenced by the size of the institution, the selectivity of that institution, and the region of the country in which it is located (Maureen Hallinan, Department of Sociology, University of Notre Dame). Learning is inhibited when the values, norms, and expectations of the student "come into clash with what we are at the moment doing in institutions" (Rochel Gelman). This point was underscored by some participants with respect to the rapid pace of change that has occurred in some institutions. Change should proceed in an orderly fashion, because "radical change in course design breaks an unwritten social contract between faculty and students" (Jill Larkin).

As will be developed in the remaining sections, developing educational technology has a lot of potential for students in higher education. However, in the short run, technology scares a lot of students (Rochelle Gelman), and the heavy use of technology scares more women than men. "What we need from the social sciences is some architectural perspectives on how to make technology work" most effectively (Uri Treisman, Department of Mathematics, University of Texas, Austin, and member of the Advisory Committee for Education and Human Resources).

The Teacher

Because the teacher controls both what is taught and how it is taught, the teacher is vital. Five themes were discussed in the context of describing effective and ineffective teaching techniques.

The disadvantages of the "broadcast model of education" were discussed. Many faculty consider the prerequisites for good teaching to be met "if I know and understand my discipline, and I get up in front of the class and give good lectures, and I give good assignments" (Jill Larkin, Department of Psychology, Carnegie Mellon University). However, there is evidence to suggest that simply giving students more information does not improve learning. A preferable teaching paradigm is where teachers interact with their students and act as facilitators in the learning process.

While traditional teaching methods often attempt to counter students' misconceptions by teaching the 'correct' way to think, "curricula which take misconceptions as a point of departure rather than a road block can be more successful" (Nora Newcombe, Department of Psychology, Temple University). New techniques for teaching science should thus "arrange experiences in which students realize how different aspects of their thinking are incompatible, then work to resolve this impasse" (Nora Newcombe). This will help to counter a major problem, that many students have a "strange and impairing view of the natural sciences and mathematics," seeing them as a collection of facts that are hard to grasp (Jill Larkin). More stress on applied research in the classroom will also help, many agreed.

Research conducted by sociologists suggests "that working in groups in a cooperative setting produces greater growth in achievement that straining for relative gains in a competitive environment (Maureen

Hallinan). Thus it is important for teachers to provide students with opportunities to work in groups.

Technology, such as email and bulletin boards, provides opportunities for faculty to interact with students at a greater frequency, while Web pages provide new information resources for students. However, technological innovation is costly in terms of the "human effort that has to go into designing it," as well as the human investment of educating teachers to use these innovations (Neil Stillings). Evaluating the effectiveness of new technology in the classroom is also problematic because "we don't have quality benchmarks ... to bring these innovations together with some of our learning theories" (Kenneth Foote, Department of Geography, University of Texas, Austin).

Improving undergraduate education by teaching faculty how to teach includes helping them to effectively use everything from "the oldest and most transparent technology" of a blackboard, to "tens of thousands of dollars worth of multimedia equipment" (Daniel Goroff, Derek Bok Center for Teaching and Learning, Harvard University, and National Research Council). Improving undergraduate education entails that teachers as well as students invest in learning new skills. It is important to use technology effectively, to promote interactions among students, faculty, and material, and to avoid using it as merely another method of broadcasting information to passive student recipients. In learning to use technology, and use it wisely, many older faculty are seen as irretrievably lost, while younger faculty typically recognize that print media is losing its effectiveness (Andrew Abbot, Master, Social Sciences Collegiate Division, University of Chicago).

Curriculum

Much of the current curriculum of the sciences, mathematics, engineering, and technology in college courses "follows an instructional paradigm, not a learning one" (Luther S. Williams, Assistant Director, NSF). The following themes focus on how curricula can facilitate learning by students.

Students interpret new information in the context of what they already know. However, students in a classroom begin from different places. To promote learning in the classroom, faculty must provide "stepping stones from the minds of our students who may not overlap" with the structure mapped by teachers, "to the point where they have in fact achieved understanding that they didn't have in the first place" (Rochel Gelman). Thus, the content of the curriculum should be flexible enough to accommodate students' different learning styles and starting points.

In many institutions, the majority of students fulfill science requirements through social science courses. The "social sciences tend to be great fields for hands-on experience with science" (Neil Stillings). To the average undergraduate, the social sciences offer better accessibility to knowledge relative to the physical and biological sciences. "… It's very important to put students in a context where they can connect their understanding of physical and biological knowledge with social life, with the life of the mind, and that means we have to put them in classrooms where things about the brain and about behavior genetics are being taught together with things about behavior and society so that they can make that connection" (Neil Stillings). If the study of experimental design and statistics in the social sciences are combined with topics in cognitive science such as causal reasoning and normative models of thinking, and this is done effectively, then greater numbers of students will achieve a reasonable level of scientific literacy by grasping the significance of these connections. Also, "cognitive science is a good vehicle for teaching a lot of mathematics and computer programming" (Neil Stillings). Thus, in general, students benefit from a curriculum that has an interdisciplinary approach.

However, “beyond the question of the social sciences contributing to the broad issue of the learning of science ... we have to give increased emphasis to the social sciences themselves” (Luther Williams). Despite the promise of the social and behavioral sciences as a metaphor for buttressing student understanding of the physical and biological sciences, there are problems specific to these fields that are more extensive than found today in the natural sciences, namely, that passive learning is perhaps more widespread, and basic research on curriculum and learning in these fields is considerably behind. This may be due to the fact that a growing majority of high school graduates now attend college and enrollments in the social and behavior sciences have been swelling. Consequently there is less introspection about student learning than is found in the natural sciences and engineering.

To achieve significant and lasting improvements in undergraduate education, we must be able to pinpoint whether students successfully learn curriculum content. Many students have the idea that “understanding something is kind of being familiar with it” rather than trying “to really master something” (Jill Larkin). From the perspective of most faculty, current forms of evaluation often mean that “we give an exam, hand it back and then go on with the next lecture (Jill Larkin). This does not tell us, in general, whether mastery of the material has been achieved. Successful evaluation should include a feedback loop where faculty and students together can determine the extent of mastery.

Institutional Context

In order for undergraduate education to improve on a large scale, the institutional context in which it takes place must be examined. Change is more likely to occur if it is supported at the institutional level. The following themes suggest some ways to accomplish this objective.

The potential for systemic reform has been improved by the development of new educational technologies. New teaching models, often incorporating some of the potential of new technology, “cut across traditional disciplinary and really university boundaries” (Kenneth Foote). With the appearance of the Internet and the Worldwide Web, the walls of departments and universities must be permeable enough to “cultivate ... more types of local, regional, and national collaborations” (Kenneth Foote). Institutions that promote these kinds of new linkages are more likely to benefit from new technologies and ideas.

Cost constraints already are demanding that most universities have large class sizes, despite evidence suggesting that smaller classes have an environment more conducive to learning. Thus, administrators of institutions of higher education need to “start to think about how to facilitate these kinds of needs within the environment” of large class size that currently exists in many institutions (Rochel Gelman). Investment in technology may allow for students and faculty to have more interaction at a lower cost by providing “other ways to communicate the same type of lecture material” (Ronald Ehrenberg, Vice President for Academic Programs, Cornell University).

In the existing institutional context, “we don’t have good integrative mechanisms for thinking about making sensible decisions about how to affect the trajectories” or paths that students take throughout their undergraduate education as well as after they leave (Melvin George, Chair of the Subcommittee of the Subcommittee of NSF Advisory Committee for Education and Human Resources). We must focus on issues of choice of major and course-taking, and pay increased attention to the high percentages of students who do not complete their undergraduate education.

Meanwhile, the discussion continued to emphasize that though the pace of institutional change is accelerating, it is important to retain the “human touch” of contact between faculty and students. There has been a lot of research on the impact of mentoring on student achievement and persistence that informs us that careful mentoring is a powerful force. Furthermore, even modest indications of faculty interest in their students and student learning outcomes have a big impact on student effort and persistence. For example, faculty tend to get high marks on student evaluations even in courses with difficult material and examinations if the faculty have demonstrated a minimal level of caring, for example, being able to call on students by name, keeping track of class attendance, and demonstrating a willingness to discuss problems outside of class time.

The Social Sciences and Undergraduate Education

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There are two aspects to the role of the social sciences in undergraduate education. The first is the place of the social sciences in the content of instruction. The second is the contribution of social science research to understanding the impact of undergraduate education on those who are taught.

Social Sciences in the Curriculum

Of the place of the social sciences in the content of undergraduate education there is little doubt. In the ideal curriculum, the social sciences are both an essential, freestanding constituent of "core learning" and an important subset of majors for upper level students. That is, the social sciences are crucial to both general and specific education at the undergraduate level. In my own university, social sciences constitute six courses in the required curriculum of 22 (of 42 total) quarter courses, and social science majors constitute the plurality (about 42 percent) of undergraduate majors.

At the level of general education, the social sciences raise two kinds of issues. In our curriculum these are contained in the two different required sequences: core and civilizations.

Our core sequences inquire into certain basic problems of social life: individual and group, freedom and determinism, equality and inequality, personality and culture, difference and similarity. The exact content of our five core courses varies, although there is a tendency to focus on classic texts and on particular modes of inquiry. What does not vary is the classroom structure and pedagogical technique. The classes are small (maximum 25-30), are taught largely by Ph.D.-level faculty (about 75 percent), and are largely discussion-based. This reflects our strong belief that general education is not about content but about the skill of critical reading and thinking. We aim to create citizens who can think clearly, critically, and creatively about the social life that surrounds them. This can be accomplished only in small classes, where faculty can intimately model the process of reflective thought, and where students' work – both oral and written – can receive the detailed comments that alone promote effective learning.

Each of the five core sequences has a number of "tracks" – from five to fifteen at any given time – taught by individual faculty. Within a course, tracks share about 70 percent of their curricula, so that student learning continues in the dormitory and lounge as students from different tracks argue about common themes. Across tracks, faculty meet weekly to discuss pedagogy, to argue about text materials, and to plan future curricula. Such staff meetings offer an important resource to faculty, both in terms of sharing of pedagogical secrets and in terms of interdisciplinary learning, for the courses are generally staffed across disciplines.

The five core tracks really shake down to two curricula: Plato-Aristotle-Machiavelli-Locke-Hobbes-Marx and friends and Smith-Marx-Durkheim-Weber-Freud and friends. From time to time, we have also had a core sequence based on empirical social science, which takes students from a quarter on philosophy of inquiry through a quarter on actual social science research to a quarter on policy. Even in such a sequence, however, the focus continues to be on addressing basic questions; classic texts continue to provide an organizing role, augmented by doing actual social science research.

The other required social science sequence is civilization; a much more complicated pedagogical structure. There are three teaching rationales behind the civilization sequences: a concern with contingency and diversity, a concern that students contact a culture or cultures different from theirs, and a concern that students truly understand their own culture, whatever that may be. Two of our civilization sequences are taught in "core format," as just described: Western Civilization (about 40 percent of students in 16 tracks) and American Civilization (about 10 percent of the students in 4 tracks). The others are taught in the more standard lecture/recitation format. All, however, tend to focus on classic texts. These are reviewed and updated periodically. (Those for American Civilization are on-line, for example.)

The civilization sequences (the largest eight of them cover 95 percent of the students) generally involve history and anthropology faculty. For faculty, the problems of curriculum planning and design again produce the interdisciplinary contact of the core courses. For students, this interdisciplinary gives rise, again, to a complicated, nuanced approach to learning.

Beyond the required curriculum, we also have, as I noted, a steady 40-45 percent of the majors in the College. As in most colleges, the largest is economics, but social science in fact dominates the University of Chicago undergraduate scene; we have four of the largest six majors (economics, political science, psychology, and history). Extensive research, which I mention below, shows that students treat their majors essentially as an advanced form of liberal education. Most of our students do not perceive their choice of major as related to a career decision. (Two-third of our premeds major outside biological sciences, for example.) As a result, learning in the majors is driven again by the problem of mastering a specific body of skills and thinking, the skills and thinking of advanced inquiry in a particular field. It is this specific discipline, not the content that alumni report as important in their later lives.

The center of this specific learning is the B.A. paper, required in most of our majors. At its best (in our history program), the major introduces the student to the problems of advanced thinking with a junior colloquium, then advances by associating paper-writing seniors with preceptors at a ten to one ratio. The resultant papers are read and improved by faculty in their later drafts, once they have been effectively pre-prepared. Other majors work essentially like mini-curricula, with introductory sequences, methods courses, and upper-level electives. In general, our majors are effective but "quick" curricula. The exigencies of the core, the tendency of students to front-load their science requirements (we require year-long sequences in BOTH physical and biological science), and the tendency of many students to switch into social sciences late in their career. It means that the social science majors must move students through the discipline of advanced knowledge faster than is done elsewhere.

It should be noted that our curriculum assumes that the social sciences are an independent area of knowledge, between the social sciences and the humanities. They are not a stepchild of either, but rather proudly freestanding. In part this reflects institutional history; we are perhaps the only major university in which the social science departments enjoy higher national rankings than those in either humanities or natural sciences, a situation that has persisted from the 1920s. Moreover, the curricular structure has been etched into the internal administrative organization since 1929, when Robert Maynard Hutchins divided the faculty into Divisions (Humanties, Social Sciences, Physical Sciences, Biological Sciences), each with a Dean responsible for graduate teaching and general oversight and (since the end of a separate College Division in 1963) a Master responsible for undergraduate teaching and the College's half of the personnel jurisdiction. We have no faculty of Arts and Sciences and no overarching Dean. Divisions report to the

Provost.

Thus a central question of this [EHR Advisory Committee] Review – whether the social sciences can serve as a vehicle for "science education" – is ruled out of court. Our faculties do not feel that social science learning can be collapsed into natural science learning or vice versa.

Social Science Research and the Undergraduate Experience

In the area of research on the curriculum, however, the social sciences have much to say. I here report on a large investigation under way at Chicago with the help of the Ford Foundation.

Three years ago, the Foundation provided us with a grant for the support of social science majors at the University. (This was part of a larger program involving a number of leading universities.) With this funding, I have undertaken a large body of research aimed at two fundamental questions, neither of which has ever seen much study.

The first and simpler of these questions is that of origins. Nobody seems to have asked why we have majors in the first place. There was one dissertation, long ago, on the subject. I have supported research into the history of majors with an idea to finding out the original pedagogical rationale as well as the administrative forces driving the change. It has indeed proved that to a considerable extent we have majors because we have departments, majors proved a way of solving the administrative problem of regulating universities that, for the first time, had numbers of faculty concentrated in particular areas. On the other hand, majors were also a crucial part of reining in the chaos of the electives-based curriculum of the late 1 9th century, and in that sense an alternative to the core-based programs (at Columbia, Chicago, and elsewhere) that attempted the same structuring of the curriculum but in a different manner. Other than the conflict with core-based curricula, there has been no serious challenge to the idea of majors in the 20th century. As with the graduate intellectual life, however, it seems that there is much more overlap in the actual contents of majors than in the disciplinary origins of the faculty teaching them. On the ground, considerable interdisciplinarity has probably been the normal state of affairs.

The second and more difficult question we have addressed is the impact of the major on the later life of students. Because Chicago has had for at least twenty years a curriculum with both a serious core and serious majors, we are able to ask specific questions about the relation of these for students in choosing Chicago, in studying here, and in their later lives. Ideally, such research should be prospective, and I would certainly propose that for the future. But at present, we have mounted a large "synthetic cohort" examination of the problem.

This analysis includes the following components:

1. A survey of the class of 1995
   - 300/700 responded information on parents' majors, employment, hopes for children on respondents' aims in high school and later, choice of major, choice of career, satisfaction with education, etc.
2. A sequence analysis of exact transcripts of 1995 class (entire) to study changing of majors, juggling of required curricular elements, the actual "experience" of education in terms of order and structure.

3. A survey of all alumni who have been out 2,5,7,10,15,and 20 years 1400/3600 responded (still coming in)
    - information on parents' majors, employment, hopes on respondents' choice of major, impact of major and of core on later occupational and intellectual experience (we have data at the level of specific intellectual skills – problem analysis, writing, creativity, etc.)
4. A diary project
    - ten students have kept detailed diaries of their educational experience across three years.
5. A retrospective course examination
    - twenty-five students (1996 seniors) will prepare essays discussing their experience in retrospect.

These data will permit us to examine the impact of different parts of the curriculum on later experience.

Our central research questions here all involve the "trajectory" of education; a topic that seems relatively little studied. Questions include:

1. How are core and major related to later occupational life?
2. How is core and major related to other parts of respondents' lives? citizenship? participation in cultural life?
3. How do students imagine their college careers?
4. How does reality cut across students' expectations and early college experiences?
5. What are the impacts of parents' hopes and dreams on students' lives? are these specific to specific ethnic groups? occupational types?
6. Which parts of the curriculum produce or support which kinds of skills in adult life?

The underlying vision here is one envisioning education as a process and seeking the forces that channel that process in a particular direction. My own expectation is that skills training lasts far longer into and proves more valuable for adult life than does specific content, and that the disappearance of major content from the horizon of adult experience is quite quick. But these are empirical questions, to be addressed only by surveying an alumni body with long-standing experience of a particular curriculum.

The University of Chicago is an elite institution. Results, and indeed research questions, will probably be quite different at another kind of university. This issue seems to me one of the most difficult facing the workshop. I am confident we could agree more on the content of the kind of education proposed here than we can either on the content of other forms of education or indeed upon the idea that education for elites and masses are likely to be fundamentally different. But the latter point – the recognition that elite and mass higher education is likely to differ – seems a crucial one. Such research as we have on learning seems to indicate that amount and quality of feedback to students is the strong predictor of good education, and effective feedback requires staff quality and intensity unreachable at most public institutions. I propose this issue without any idea of how we should address it.

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Scientific Literacy and the Social Sciences

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In a world increasingly shaped by science and technology, a fundamental understanding of science is an essential aspect of contemporary education. We can no longer talk of science *and* the liberal arts; science must be an integral part of a liberal arts education. While I suspect that there will be little debate about the importance of scientific literacy, there may be fewer consensuses about *how* this can be generally achieved. The focus of this brief presentation will therefore be on question #3: In *many institutions, students take courses in the social and behavioral sciences as a means to fulfill their science distribution requirements. In what ways can and do these courses effectively promote scientific and quantitative literacy?*

As a basis for the presentation, I will use the case study of Colgate University. Colgate is a selective undergraduate liberal arts institution enrolling approximately 2,800 students and employing about 240 faculty members. It has a strong emphasis on majors (concentrations), as well as a distribution requirement – two courses in the sciences: social sciences, and humanities and a core general education program. Of course, I choose this example not solely because of its representativeness, but also because of the availability of the data I will be presenting.

Despite the increasing need for general science education, there are currently several practical barriers to achieving this objective successfully. *First,* although there is renewed interest in the sciences among students compared to a decade ago, still relatively fewer students major in the science compared to the social sciences and humanities. Five years ago, 22 percent of the graduating Colgate students majored in the sciences; today that figure has improved to 28 percent. Nevertheless, 33 percent currently major in the humanities and 39 percent major in the social sciences. Therefore, we cannot necessarily depend on science concentrations to provide a science education for students in general. The vast majority of students do not major in science. *Second,* perhaps because of lack of interest or lack of preparation, a substantial portion of students take the minimal amount of science possible within the liberal arts curriculum. As I noted earlier, Colgate has a two-course-per-Division distribution requirement. Thirty-four percent of Colgate students graduate with only these two science courses on their transcript (compared to 24 percent with the minimum social science and 9 percent with the minimum humanities requirements). *Third,* in a time of diminishing financial resources to higher education, the costs of traditional science education are high and are escalating. At Colgate, the average department budget allocation per faculty member in the sciences is six times what it is in the humanities and four times what is in the social sciences. Start-up costs are ten times higher in the sciences than in the humanities or social sciences. Because of teaching credit for laboratories, science instructors teach only .8 of the range of courses per year as other instructors, and the sciences accommodate only about 28 percent of the total enrollments. Recently, the controversial study from the University of Rhode Island has raised questions about the overall cost-effectiveness of pursuing research grants. An Important question then becomes: *How can we provide a better general science education for students in the face of these barriers?*

The answer I propose is that the *social sciences can effectively and efficiently contribute to science education in ways that complement and support the traditional sciences.* Colgate's experiences offer some insights because it’s unusual Division structure. The Division of Natural Sciences and Mathematics consists of biology, chemistry, computer science, geology, mathematics, physics/astronomy *and psychology*. Psychology is considered a social science on many, if not most, other college campuses. Using the social sciences more effectively can help overcome each of the obstacles I just raised; the first issue involves *capturing student interest* in courses that can potentially make major contributions to scientific and quantitative literacy. Among the seven science departments, psychology's enrollments have consistently been the highest. In addition, unlike each of the other departments, it did not experience the dramatic decline in enrollments of the 1980s. Among those students taking only the minimum two-course science distribution, psychology courses are clearly the courses of choice: 73 percent of those students had a psychology course as one of those two courses. Geology was second with 37 percent. The traditional, central sciences, such as chemistry and physics were largely represented in these students’ records (3 percent and 4 percent; see Figure 2.2). The attraction of Psychology is not likely easy grades; the average grade in the introductory psychology courses is the lowest of all of the introductory science courses. Thus, social science courses may provide an inherently attractive avenue among students for achieving the essential goals of a general science education.

The curricula of some social science disciplines may also be particularly well-suited to developing general scientific and quantitative literacy because of their explicit focus on methodology and statistical analysis. Table IV.1 lists the departments in which a statistics (or mathematics course) is a required or elective course in the major.

Table IV.1

Departments with statistics or mathematics courses as required or elective courses (science departments in boldface type).

Required	Elective
Computer Science	**Biology**
Economics	Education
Mathematics	Geography
Physics	Political Science
Psychology	Sociology

The science concentrations not on this list – astronomy, chemistry, and geology – instead have required *instrumentation courses*. Although experience with sophisticated, state-of-the-art scientific equipment may be essential for students continuing on in science, the development of transferable quantitative and information management techniques may be significantly more useful to the general student who will not pursue formal scientific training beyond graduation – and can be provided effectively at a fraction of the cost of equipment, supplies, and overhead.

At the introductory course level, social science courses that emphasize the application of the scientific method and experimental approaches to verification can be as effective as traditional science courses in achieving essential goals of scientific literacy in a context or personal relevance to students. Figure 2 [projected slide not published here] illustrates a comparison of student responses (1 = “disagree strong1y” to 7 = “agree strongly”) to three statements identified by science faculty as central objectives of a general science education: (1) “The course required me to engage in scientific reasoning”; (2) “After taking this course, I am more able to evaluate current issues and problems”; and (3) “The course improved my problem-solving skills.” The responses to these items for three traditional introductory science courses (biology, chemistry, and geology) are compared to Introductory Psychology and to an interdisciplinary Introductory Environmental Studies course (reflecting an integration of areas of biology, geology, and geography). The two "non-science" courses are generally as effective – and in some ways are more eff6ctive – in achieving the general goals identified by the faculty.

Because of the hierarchical nature of science curricula, the burden of providing the prerequisite factual information to prospective majors may interfere with an emphasis on the *process* of scientific inquiry that may be an essential aspect of a general science education for non-majors. Thus curricula that offer alternative entries to the major, rather than a strict linear sequence, may offer more opportunity for pedagogical innovation and flexibility and time to devote to an understanding of the process of scientific inquiry. Among the sciences, only geology offers multiple alternative entries to the concentration. The majority of the social sciences (i.e., not psychology or economics) allow different entry points. Recently Colgate has introduced a series of pilot Scientific Perspectives courses, which are staffed by social scientists as well as natural scientists as part of the required Liberal Arts Core program. These are designed to enhance scientific literacy, by focusing on the process of scientific inquiry with the mastery of a specific body of factual information, as a secondary concern. The results of student responses to these courses, separated by those taught by social scientists (economists and psychologists) and those taught by natural scientists, are presented in Figure 3 [projected slide not published here]. These results compare favorably to the results for the traditional science courses depicted on the previous figure. Thus, teaching introductory science may not be the only or the most effective way to achieve scientific literacy among non-science majors. In addition, science literacy may be achieved at least as effectively through selected social science courses.

In conclusion, it is currently particularly important to recognize and support the role of the social and behavioral sciences in science education. The incorporation of selected social science courses to complement traditional science courses in scientific education programs is valuable because:

- Social science courses are currently attractive to students
    - the topics and issues are of immediate relevance to students
    - these courses may be accessible to a wide range of students because they normally do not rely on pre-requisite high school preparation
- Social science courses may provide a cost-effective alternative
    - these courses normally have lower start-up equipment expenses and reclaiming costs for supplies
    - these courses do not normally require dedicated laboratory space; when equipment (such as computers, network links, graphics equipment) is needed, it frequently can be used for multiple other purposes
    - the skills that are acquired in laboratory experiences (e.g., computer or networking skills, skills in information retrieval, evaluation, and management, and skills in quantitative analysis) are highly transferable skills that will benefit students beyond graduation.
- The social and behavioral sciences may offer curricular and pedagogical flexibility
    - this flexibility may allow the adaptations needed to meet the needs of non-science students
    - more flexibility in the amount and nature of information presented can permit a more deliberate and self-conscious examination of the scientific method, experimental procedures, and data analysis
    - the topics of study may offer more obvious and direct connections to the use and misuse of scientific information and technology
    - the use of less structured laboratories can encourage the use of a wider range of pedagogical strategies, such as cooperative learning and creative problem solving.

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Why Study Economics? Why Teach It Using Frontier Technology?

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Teaching Introductory Economics at Cornell University Using the Worldwide Web

Cornell University has revamped the way it teaches Introductory Microeconomics using Worldwide Web technology. Partially as a result of the need to conserve faculty resources, Cornell reduced the number of lecture sections of Introductory Microeconomics that are taught throughout the University and increased the average lecture class size by roughly 50 percent (from 250 to 380). My colleague, John Abowd, who is a continual NSF Economics Program grant winner and a former NSF Economics Program Advisory Committee member, assumed responsibility for one of the classes. He did so motivated by the belief that students at selective research universities should be exposed early on in their education to prominent researchers and that they should be taught using frontier technologies.

Abowd's course is structured as follows:

On the first day of class students are given a multiple-choice exam that tests their knowledge of, and ability to apply, all the concepts to he learned throughout the semester in the class. Scores on each question for each student are stored on his server for future use by him.

Students are forced on to the Worldwide Web as lecture notes for the class are placed on the Web in advance of the professor's in-class lectures. Not surprising, attendance is lower than one observes in comparable size classes in which the lectures have to be attended to learn the professor's views. However, as noted below, Abowd can actually test if attendance, *per se*, improves performance.

Given the scale of his class, Abowd has enough teaching assistant (TA) resources to conduct office hours for multiple hours each day. Cornell is located on a very spacious campus and while the TAs are physically located in one room, students do not have to actually go to that room to see them. Rather, they can go to any one of a number of locations on campus and be "connected" to a TA using a computer technology that allows two way audio and visual contact between the students and the TA. Alternatively, they can communicate with the TAs by electronic mail.

Whenever a student asks a question relating to a point in the lecture notes, a star is placed on that spot on the Worldwide Web copy of the lecture notes. By "clicking" on that star *any* student in the class can read the question and see the answer. Effectively, use of the Web has multiplied the value of office hours. All students now have the potential to learn from the questions of any one. In the language of economists, office hours, which once were a private good, have become a public good.

Periodic exams are given in the course. Some of the questions are, in fact, identical to those given on the pretest. Thus Abowd can learn which specific concepts/questions are the ones that the students are having the most difficulty learning. Put another way, he can learn which sections of the lectures confuse rather than clarify things. Given the students self-reported class attendance, he can also estimate if attendance *per se* influences what students learn.

Weekly problem sets are given in the form of spreadsheets found on the web sight and answers must be submitted over the web. While students have complained about being forced to learn a new technology that is not essential to economics, they quickly master it and then observe how spreadsheet programs facilitate "what if?" discussions.

This course has not been an easy one to get off of the ground in spite of the Herculean efforts of Abowd for a number of reasons. First it has required a substantial initial capital outlay for equipment, including remote teleconference sites. Individual departments do not have the resources needed to develop such equipment funds; the university as a whole has to at least be partially responsible for them.

Second, it has required funding for all of the Web programming for the lecture notes, problem sets and exams. While it is rapidly getting easier to translate word processor files into Web-compatible format, this is not something that most "mature" professors feel themselves capable of doing. Many new undergraduates have mastered the technology and they provide the necessary labor pool for this activity.

Finally, Abowd is easily among the top 5 percent of all Cornell professors in terms of his facility with new technology. Once he has created the course structure, other colleagues can adapt it for their own courses. But how many of us will? And who will pay for the extra support costs such courses entail? Our saving in faculty time is only a saving to the university if we reduce the size of the faculty and/or use the freed up faculty type in some other revenue producing activity (e.g. off-campus learning or continuing education on campus). So far, most faculty and universities show little inclination to do either.

The Importance of Economics in the Curriculum

Research by economists (some of it funded by NSF) has demonstrated that the likelihood that any individual will spend his or her career with a single employer, or even in a single occupation, has declined in recent years. To have a successful career, individuals must be flexible and adaptive to continually changing technologies and economic forces. Learning to become accustomed to the former while in college may be almost as valuable to students in the long-run as the subject matter they study.

I say "almost" because I strongly believe that it is important that students study economics in college. Economics provides a conceptual framework that they can use to analyze private and public decision problems throughout their lives. Such basic (to an economist) concepts as demand and supply, the tendency of markets to move towards equilibrium, maximizing behavior under constraints, marginal analyses, externalities, opportunity costs, the prisoner's dilemma, the importance of relative prices, moral hazard, unintended side affects of decisions, adverse selections and rational expectations provide students with "tools" to help them evaluate their own private decisions and the issues they read about in the newspapers that policy makers continually face.

I regularly taught a course at Cornell for about 15 years called the "Evaluation of Social Programs." For six weeks I dazzled the students with my knowledge of quasi-experimental design and Campbell and Stanley's "threats" to internal and external validity. Showed the students how to implement the designs in the context of regression models and how each of the "threats" corresponded to an econometric problem, demonstrated how to compute sample sizes needed to obtain statistically significant program effects, and finally introduced them to benefit/cost analysis in a social context. I then spent the final eight weeks applying these models and techniques to the evaluation of labor market programs and policies, always using simple microeconomic models to conceptualize things. By the end of each semester I was always convinced that I had "wowed" students with how much I knew and with how exciting social policy analysis was.

Several years ago I ran into one of my former undergraduate students, who by then was high up in the human resource department of a major corporation. He told me that my course was the most valuable course that he had taken at Cornell and that he used concepts from it regularly in his work. I was dumbfounded. My course dealt with social programs; he was working for a private corporation. Ultimately I realized that he understood much better than I did what the course was really all about. Our job as academic economists is to increase our student's analytical abilities, not to cram them full of specific applications that interest us. Fortunately, the tools of economists are sufficiently useful that sometimes students understand this point, even if we don't ourselves.

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Social Science Education, Information Technologies, and Virtual Universities

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I wish to concentrate on only a few of the issues that are the focus of today's agenda. My stress will be on technology and the way it is transforming the entire learning process, affecting our vision of how and what to train students, and changing our repertoire of best practices. First I want to draw attention to the role of the social, behavioral, and economic disciplines in basic science education.

On my campus, the fact is not always appreciated that the social, behavioral, and economic sciences play a major role in basic science education, whether measured in student numbers or innovative projects. For a large cohort of students, basic science requirements are met by courses outside of the natural and biological sciences and engineering. Instead, their contacts will arise from courses in sociology, demography, anthropology, archeology, psychology, economics, geography and the like. Even though this is the case at many other campuses too, I realize that it is not always weighted as heavily as it perhaps should be in efforts to improve scientific literacy and the quality of the American scientific workforce. Yet within these disciplines, faculty is clearly concerned with these issues. They are taking the challenge of scientific literacy to heart and developing very promising models that address the broader concerns of general science education, in at least two ways.

In the first, stress has been placed on cultivating the analytical and problem-solving skills of students through active learning strategies. Too often, science curricula seem to value mastery of content over comprehension of the process of research and investigation. New prototypes seek to redress this situation and reassert the importance of cultivating analytical reasoning skills in the undergraduate curriculum. Social scientists are using small-group learning techniques and collaborative problem-solving to engage students in active debate and investigation of pressing scientific, political, and social issues.

Second, many social scientists are attempting to span disciplinary boundaries by challenging students to consider concepts and issues from interdisciplinary perspectives. The sense here is that conventional disciplinary boundaries are increasingly blurred in both theory and practice and students must learn to apply conceptual and analytical skills from many disciplines, rather than those of a single field. These projects often rely on a team of faculty drawn from several departments to address a single important and interesting topic, such as sustainable development or environmental quality, from a variety of perspectives. All of these projects take a fresh look at the curriculum and attempt to move away from compartmentalizing knowledge within time-worn disciplinary categories. Such projects are likely to increase in number and scope in coming years as means of reintegrating specialized undergraduate curricula.

The Impact of New Technologies

Some of the most exciting curriculum development projects involve creative applications of information technology. As recently as a few years ago, information technology was equated solely with the use of microcomputers in traditional quantitative subfields such as econometrics, demography, experimental psychology, or my own field of geographic information systems.

But it is now apparent that information technologies are rapidly and irreversibly transforming higher education and the ways in which students and scholars learn, teach, communicate, conduct research, disseminate knowledge, and serve the public. Scholars from all disciplines are experimenting extensively with multimedia, hypertext, Internet resources, distance learning, and many other techniques that fall under the broad heading of information technology.

Hypermedia authoring techniques have just recently become accessible to large numbers of scholars and in the past two years Internet and the Worldwide Web have made it possible to develop high-quality on-line course materials. As the academic community masters these resources, experiments will go even further. It is now easy to envision "virtual" departments, disciplines, or universities in which ready access to educational resources of all sorts is available through an easy-to-use graphical interface. The idea of using the Internet and hypermedia resources to link faculty and students from many departments and universities is, in some respects, just around the corner. Such cooperative endeavors would not only expose students to a richer educational environment but also help to average out the high development costs of hypermedia resources. This summer I am starting up NSF-funded Geography Virtual Department Project. Over the next three years, geographers from all over the United States will gather at the University of Texas to plan and develop materials to support an entire undergraduate geography curriculum on-line in the Worldwide Web. The Western Cooperative for Educational Telecommunications has just made public a sound plan for a Western Virtual University that can begin to be realized almost immediately.

Toward the Virtual University: Needs, Requirements, and Programs of the Future

Support will be required for disciplines and entire universities as they re-invent themselves to serve new and diverse clienteles throughout the nation and world using a new generation of learning technologies, but how? It is not just a question of massive new investment. Change is taking place so rapidly that large investments in unproved technologies can be very risky.

But, unfortunately, a wait-and-see attitude is just as risky. It can jeopardize the lead American universities have assumed in cyberspace. My suggestion is to look carefully at the processes of change themselves. If these new technologies are to benefit students and society through the educated used of information, people and systemic reform of institutions will be as critical to the process of change as the evolution of the underlying technologies. The "virtual university" must be viewed as the product of a process of change across the entire knowledge base of higher education. The transformation will involve:

1. Active collaboration of faculty, students, and staff in the development of new teaching and curriculum models and materials that will link across traditional disciplinary and university boundaries and result in systemic change of undergraduate and graduate education.
2. Careful evaluation and testing of prototypes including the cultivation of new modes of peer review, planning, and collaboration.

3. Comprehensive support for time invested in developing these new models including equipment, staff, and rewards that cut across conventional distinctions among educational, research, and public service.
4. Sustained support for collaborations and partnerships that will contribute to and draw upon far broader efforts to interlink advances in K-12 and collegiate instruction at the local, regional, national, and international levels.

This means that some traditional distinctions are gradually losing their relevance. Even the clearest divides among disciplines are disappearing as faculty and students build intellectual bridges electronically. Separate universities are finding themselves no more than a click away from one another on the computer screen. The sharp distinctions that were once made among research, teaching, and public service have blurred substantially. The most pressing question in this situation is what can be done at the national level to insure that these changes support the nation's lead in science education. Attention should be give to programs that:

1. Stress systemic reform of science education within individual institutions by reinforcing collaborative linkages among disciplines and approaching the knowledge-base of higher education as more than the simple sum of the social, behavioral, economic, biological and natural sciences. A strong faculty enhancement component is essential so that faculty can gain the skills and support needed to make a success of these efforts. American universities have never before been asked to "retrain" faculty on the scale they are today. It will be very important to adjust the academic rewards system to recognize this fact
2. Promote innovative educational partnerships at all levels to highlight the fundamental relationship between K-12, collegiate, and graduate science education. Such partnerships might also benefit from close connections with business and industry. Consortia must be cultivated at the local, regional, and national levels.
3. Establish rigorous benchmarks for the review, testing, and evaluation of these internal linkages and external partnerships. These benchmarks must be suited to the demands of new modes of technology enhanced learning and must address both the process of development and the products that are created.
4. These internal linkages, external partnerships, and quality benchmarks must be conceived with an eye toward broader education horizons, both temporally and spatially. What are needed are models and prototypes that can be scaled up to encompass the emergence of other linkages and partnerships through time and are robust enough to be applied to many different types of institution all across the country.

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Contributions to the NSF Social Sciences Workshop

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The last twenty years or so of research on learning and cognition has born witness to a theoretical sea change. The widespread view that the mind absorbs whatever data it is offered has given way to an alternative. This is that the mind actively selects, interprets and even creates environments with reference to existing knowledge bases.

These active tendencies of mind are pervasive; they reveal themselves as much in studies of social cognition as they do studies of learning about mathematics and physics. When the same news clip is shown to Israelis and Palestinians, both report that it is a biased presentation in favor of the other. When fractions are introduced to the curriculum, children interpret them as novel examples of the natural numbers, reporting that 114 is more than 1/2 "because 4 is more than 2" or 1/76 is more than 1/65 "because 76 is more than 65." We are more inclined to attend to things we know something about; we interpret what we encounter with reference to what we already know. These active tendencies of mind have deep implications for education.

Educators no longer can assume that they material they offer learners will be interpreted as intended. Whether or not learning proceeds depends heavily on whether there is structural overlap between what is already known and the to-be-learned body of knowledge. When there is overlap, there is a reasonable chance that students will move along domain-relevant learning paths. When there is not overlap, there is a non-trivial chance that students will unwittingly misinterpret what they are offered, often enough in ways that are hard to anticipate. For example, it never occurred to me that my undergraduates would "hear" Kant as Can't. (I now write Kant's name on the board when I first introduce his ideas about knowledge and learning).

These facts about cognition are especially relevant to our discussions for today. When our goal is to teach a new body of knowledge to undergraduates expertise in one's discipline does not guarantee success in the classroom. The odds are high that there are qualitative differences between the knowledge structures of learners and teachers. Indeed, there is reason to anticipate gaps between learners and learners given our commitment to universal literacy be it in the humanities, social, physical or biological sciences, sciences, humanities. I will expand on this point in my remarks about the way that cognitive research can facilitate the goals of undergraduate education.

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Social Science Research and the Learning Process

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Learning is a function of student ability, motivation and effort. These three factors interact in a non-linear manner to produce knowledge. In addition, learning takes place in a social context, which differs for each student by their ascribed and achieved characteristics. The contribution of the social sciences, and sociology in particular, to an understanding of how to improve undergraduate education is based, in large part, on the research that has been conducted on the various components of this learning model.

In general, psychology has led the social sciences in broadening our understanding of student ability. Recent research on the nature of intelligence has challenged old narrow definitions of intelligence that were almost solely related to analytical abilities and to cognitive thinking. Identifying different bases for intelligence and for understanding the world has made a significant impact on attitudes toward the learning process and toward achievement. More research needs to be conducted in this area, both to increase our understanding of intelligence and to disseminate this work to educators. The implications of this work for curriculum content, pedagogical techniques and performance evaluation are profound.

Psychologists also have made significant advances in understanding of individual differences in learning strategies. Their research has identified several different learning styles, such as visual learners and kinetic learners, and demonstrated that the better the fit between a teacher's instructional techniques and the student's learning style, the more the student learns.

Both psychologists and sociologists have addressed the issue of student motivation. While psychologists have been concerned about intrinsic motivation, sociologists have studied extrinsic motivation in the form of rewards and sanctions. Sociological research has examined whether students are more motivated in cooperative or competitive environments and working individually or in groups. Findings suggest that working in groups in a cooperative setting produces greater growth in achievement than straining for relative gains in a competitive environment.

Motivation also is affected by student interest in the subject matter. Sociological research on the organization of instruction in secondary schools demonstrates that the higher the quality of instruction, the more interesting the curriculum and materials, and the greater the amount of time exposed to the curriculum, the greater the growth in achievement. The social organization of students for instruction affects the quality and quantity of instruction. Organizational arrangements such as ability grouping and tracking at the middle and secondary levels have been shown to differentially channel opportunities to learn to students who differ in ability. The higher the ability group or track level, the higher the quantity and quality of instruction and, even with ability controlled, the greater the growth in achievement. At the college level, the quantity and quality of instruction also varies across courses. Access to the most favorable learning situations varies by student characteristics, such as ability, and linkages to faculty and peers who can provide relevant information about courses.

Another factor affecting student motivation is the influence of peers. A large body of sociological research demonstrates that peer groups are a significant factor in the learning process. Students who belong to a peer group that devalues academic work are less likely to succeed academically than those who have peer models who are serious about academic achievement. Peers affect the amount of time spent studying, the nature of non-academic activities (wholesome or dangerous), the choice of courses, educational aspirations and academic achievement. Some studies show that school personnel can modify an anti-academic peer culture through the creation of desired rewards and through the expansion of the bases for social hierarchies.

Research reveals that individuals differ in the relationship they see between motivation and effort. Students with similar levels of motivation may expend different amounts of effort to attain their educational goals. Coleman's research identified a race effect on students' sense of "locus of control", with black students believing that luck played a greater role in outcome than white children. Cultural differences in the value and effects of effort also have been documented. With the increased racial, ethnic and cultural diversity of college campuses, the need to take these differences into account only increases.

Other contextual variables that affect learning include the size and composition of the class. A large body of research demonstrates that the larger the class the slower the growth in achievement. The linkages between class size and academic achievement include degree of student participation in class, number of teacher-student interactions, and student self-esteem. Studies also show that the stronger the academic climate of the class, usually related to the student distribution of achievement, the greater the effort and achievement. Here, the mechanism connecting academic composition to learning involves role models and socialization.

In addition to the contextual variables that affect the dynamics of learning depicted in the learning model, individual ascribed and achieved characteristics affect learning. In a recent article in *The Chronicle of Higher Education*, Jerome Kagan cites studies showing that the components of self-esteem differ by the history and cultural background of the individual.

Similarly, the way the components of the learning model interact to produce knowledge differ by the gender, race, ethnicity, socioeconomic status and age of students. They also differ by family characteristics and by school factors. This is undoubtedly true at undergraduate institutions as well as primary and secondary schools. A better understanding of these interconnections will provide better direction to educators who design and implement college curriculum and instruction.

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The Social Sciences Contribution to the EHR Undergraduate Review: Comments on Guiding Questions

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Background

Personal experience underlies many of the following comments. Therefore, I provide here a brief summary of the most relevant experience.

The Carnegie Mellon Center for Innovation in Learning

Carnegie Mellon University provides funds for a center with a charge to use research results, experimentation, and technology to improve education at Carnegie Mellon. Four tenured faculty, as well as one senior scientist, have full- or part-time appointments within the Center. Other faculty may apply for one-semester sabbaticals at the center. During this time they work to improve one or more undergraduate courses, and gain general expertise in the science of education, which they can continue to apply to their work and share with others in their department. These faculties remain associated with the Center as “affiliates” and have desk and computer space to continue to work there when they wish.

The center also supports graduate students and post-doctoral fellows who work jointly with CIL faculty and an outside faculty member to apply scientific education to improve a target undergraduate course.

Applying Cognitive Science to Pre-College Education

For six years I headed the James S. McDonnell Foundation's Program in Cognitive Studies for Educational Practice. It provided good support (~$300,000/yr for three year terms), for cognitive researchers to begin to move research results towards pre--college classroom applications. The program produced some stunning examples of how well this approach can work. (See, Bruer, J. and McGilley, K.)

Developing an Innovative Introductory Course in Cognitive Psychology

Over the past 12 years I have taught an increasingly innovative course which provides an introduction to cognitive psychology. I organize the course around three main models appearing in modern cognitive psychology (network models such as ACT, rule models such as Soar and CAPS, and neural or parallel-distributed processing models).

The student body is diverse, including students from all four years and all five of the “colleges” of Carnegie Mellon (Humanities and Social Science, Fine Arts, Engineering, Mathematics and Mathematical Sciences, Computer Science). Thus there is an enormous range in type of interest and ability to handle the quantitative aspects of the course. I have experimented extensively with technology use, and with various pedagogical methods.

At this time, I believe the course is a cognitive success, with highly mixed sociological and motivational results. By the end of the course, most students can solve problems, write essays, and answer a special kind of very challenging multiple-choice question indicating understanding of the three model-types, and ability to apply them to a variety of data and every-day situations. However, as indicated by course evaluations and student comments. Many students do not “feel” they have learned much, and are others dissatisfied with the course format.

What other research efforts in the social and behavioral sciences inform us about the learning process?

Social Psychology

Social psychology has had little attention from scientific educators with consequences that are now becoming obvious. Everyone I know who dramatically restructures an undergraduate course initially experience hostility and unhappiness from the students. (A recent report in *Science* dramatically documents this effect for NSF sponsored introductory calculus courses.) However good the instructional design, and even the instructional effectiveness, unhappy students are undesirable. Ultimately courses that students don't like are not viable.

We need to understand how school-sophisticated undergraduates’ view their “social contract” with a professor. What should and should not happen and why? Can we work with students' expectations instead of against them? Can we exploit other features of the student-professor relationship in achieving good learning outcomes? This is uncharted territory, and crucial to continued success in applying results of behavioral science to improve instruction.

Applied Research

The McDonnell Program (briefly described above) was successful because it recognized an area ripe for exploitation and provided realistic funds to attract first-rate scientists to attack the problems of doing the exploitation. Research results do not jump to classroom application without several years of experimentation, and trial and error. Prototypes must be expanded to coherent curricula. Materials appealing enough in the laboratory must now catch and hold attention of more varied students in an environment with many distractions. New methods, practical for groups of students must be developed. Through this process, one wants to avoid simply trying to make a curriculum, but to maintain a goal of keeping the instruction tied to learning principles. Without this, the result is merely one more curriculum, and not a contribution to the science of education.

Meta-Knowledge of Science

Students have well-known misconceptions in both physical and behavioral sciences (e.g., the so-called “cognitive illusions” in probability). Less well documented, but apparent to all thoughtful teachers, are students' misconceptions about the goals and nature of science. Most students believe science is a collection of facts and rules, and that their learning task is to memorize some of this collection, perhaps along with some straightforward ways to apply the rules.

The behavioral sciences can, in my view, provide a particular opportunity for teaching how science works. Introductory physics (for example) teaches a well-developed theory that has been stable for many years. It may look to students like immutable fact, unconnected with human enterprise. In contrast, the younger behavioral sciences involve smaller scale models, which are regularly challenged and modified as new experimental evidence appears. Most students find this sequence baffling at first. (But in Chapter 3, they said...!) But this confusion gives an entree to discussing science as a process for better describing observations.

Most students lack the ability to construct a scientific argument, including data, theoretical statements, and links between them. We have repeatedly observed students' omitting any or all of these components in both history and psychology.

General learning skills

Just as students lack knowledge of the nature of science, and often have misconceptions that interfere with effective learning, there are parallel problems in students' knowledge and beliefs about learning.

Passive Learning

Many students see learning as a passive process. They attend lectures, read assignments. Study consists of ... “sitting somewhere comfortable, preferably in bed, and paging through notes and textbook” – quote from a parent. The idea that learning requires active practice seems often entirely foreign. “It's a strange thing with this course. 1 don't understand what's going on until after I've done the homework and taken the exam” – email from a student in my psychology course. “I've learned twice as much in class as in the other two Psychology courses combined. The reason is that this is a hands-on course. Here I've *done* things” – paraphrase of a comment from another student in the same course. Students' model of understanding often seems to be mere familiarity with the terms and phrases.

Failure to Learn from Errors

Students too rarely have the ability (or the motivation) to use mistakes as an opportunity for learning. For example, in my course, if a student believes there is a correct explanation for a multiple-choice answer graded as incorrect, sending me an explanation by email produces either a grade change (if I agree with the student) or a careful explanation of where the student's thinking is wrong. About 30 percent of the students never use this opportunity. The answers I've heard to the question, “Why not?” include: “I didn't really understand that I could do this. It's so firm in my head that an exam is an exam, and you get the grade, and that's that.” “Arguing with the professor is for grade-grubbers and poor students.” “I did so poorly I just didn't want to think about it any more.”

Although my particular treatment of tests is unusual, these quotes illustrate clearly that many students do not use test results as an opportunity to learn. (See also Gagne, E., *Cognition & Instruction*) We need to teach students how to use errors as a cue to their own misunderstandings, and how to work towards detecting and preventing similar misunderstanding in the future.

Lack of Even Primitive School and Learning Skills

Colleagues who regularly visit many classes at Carnegie Mellon tell me that 40-50 percent attendance is common, and that of those present, there are still the sleepers and the note-passers in the back. I have reluctantly developed a system of requiring and checking attendance (collecting a class assignment in each lecture). Many students have great difficulty taking notes, especially on class discussion. And, as reflected by some of the previous comments, many have little idea how to study.

Specifically, I believe that many of my students have no idea how to study “actively.” I suggest repeatedly a technique of working either with oneself or a partner to generate and answer questions about the material. I show a method for generating such questions. We maintain a bulletin board where students post questions they can't answer. Sometimes other students answer. Ultimately I either endorse some students’ answers, or provide comments of my own. But, as indicated by some of the comments quoted above, this is clearly not an activity many students use.

The difficulties are almost certainly both cognitive and social or motivational. The methods of effective study are certainly as difficult as the methods of psychology or physics. We need to analyze them and teach them effectively. But, even more than subject-matter procedures, these must be procedures students are motivated to use. Thus again, I emphasize the need for more social psychology to use as a base in improving instruction.

In many institutions, students take courses in the social and behavioral sciences as a means to fulfill their science distribution requirements. In what ways can (do) these courses effectively promote science and quantitative literacy?

Difficulties

1. Traditional teaching methods (lectures & reading)
   The student is passive, except for one or two exams, and perhaps a term paper.
   There is no weekly homework, often any regular discussion sessions. If there are discussion sessions, the teaching assistants may receive little or no training or guidance.
2. Little background of basic research
   There has been little research in cognitive processes in these arenas (and little financial support for such work). Thus we must translate from research in other fields (e.g., physics, mathematics), and begin some basic research in these areas.
3. Current textbooks
   - Textbooks (at least in psychology) usually have a historical organization, and do not integrate material so as to make it easier to learn.
   - Worse, textbooks often make integration especially difficult for students. For example, introductory psychology textbooks universally refer to experiments by authors' names and publication date. Since few students know automatically what Posner and Boyes did, if they wish to integrate, they must go to the author index, and then back to the page describing Posner & Boyes' experiment. Use of mnemonic titles for key experiments could solve this whole problem.

Opportunities

1. Modern social science is highly quantitative.
   Therefore perhaps we can transfer approaches similar to those effective in the physical and mathematical sciences.
2. There are educational journals in this area, which may contain useful lore to use as guidance.
3. As the behavioral sciences mature, it becomes possible to better integrate the material we teach. (See, for example, my comments on structuring cognitive psychology.

What are the ways in which technology is being incorporated into courses in the social and behavioral sciences to enhance learning and the curriculum and also to promote technological literacy?

The notes below summarize how I use technology, or have seen it used effectively.

1. *Presentation software:* sideshows, animation, integrated video material.
2. *Visualization:* before presenting formal models, I use animation to show how the model works qualitatively.
3. *Interaction software:* class response systems (Classtalk) bulletin boards; Web.

4. *Computational instruction:* computer-assisted learning, tutors, hypertext.
5. *Commercial software:* spreadsheets, graphs, outlining, and writing.
6. *Public domain research-level models*. Increasingly researchers make available their model code.
7. *Data analysis:* Many commercial packages aid in qualitative and visual as well as quantitative data conceptualization.
8. *Distribution:* Material placed on the web often gets a lot of access from surprising places.
9. *Evaluation:* (See appended essay by F. Reif.) In my course, using some computer-assisted grading, three people grade roughly 100 exams (half essay, half multiple choice) in one afternoon.

What can the social and behavioral sciences recommend that will enable faculty to meet the challenges posed by a student body that is increasingly diverse with respect to level of academic preparation and cultural background?

Long-term stable effort

Many of these issues are addressed above. A central remaining issue is how more effective practices can become available to a wider group of faculty.

The central issue, I believe, is that most faculty have a "broadcast" model of pedagogy. That is, a professor who knows the subject matter, lectures clearly provides good assignments, grades well, etc. – this professor teaches well, and the rest is up to the student. Shifting to a model of analyzing the learning task, and asking how to facilitate that learning in a particular course – this is a difficult shift of view. Once the shift is made, then there is a large body of knowledge about learning mechanisms and how teaching can make use of them. This needs to be mastered, at least in a form relevant to the professor's own teaching. We believe that this process takes at least one semester of dedicated effort, and therefore provide the one-semester "sabbaticals" at the Center for Innovation in Learning.

What are the obstacles to determining, implementing, and evaluating "best practices"?

Evaluation

I have appended an essay by Frederick Reif discussing possibilities for evaluating instruction in physics. There has been far more work in physics education than in the behavioral sciences (and far more financial support of such work). Thus the behavioral sciences may or may not be ready for such an approach. However, an effort such as Reif describes could aid in better defining reasonable learning goals, a crucial step towards improving instruction.

Collegial support

(Quoted from an abstract for a talk by Herbert A Simon) One striking contrast between our research lives and our teaching lives are that research is a highly social activity, teaching most often a solo performance. Research is carried on with colleagues, local, national and international; It's products are widely published; it is constantly judged by peers – and sometimes rewarded. Typically there is little intellectual interchange with colleagues about teaching, and few of our thoughts about it or its products are communicated.

Thesis: To give teaching the same intellectual excitement as our research (if it doesn't have it already), and equal claims on our attention, we must convert it into a collegial activity like research.

New talent

Other than the new and small effort at Carnegie Mellon, and a slightly larger effort (aimed at technology) at Georgia Institute of Technology, there are (to my knowledge) no locations for training new talent in instructional research, application, and innovation at the undergraduate level. NSF could have a big influence by providing relatively long-term training grants to establish or support centers that could train the new young talent desperately needed if we are to address any of the issues discussed above.

Jill Larkin *has joint appointments in the Psychology Department and in the Center for Innovative Learning at Carnegie Mellon University, where she also has a courtesy appointment in the Computer Science Department. Her research has demonstrated strategic differences in problem solving between physics students and expert physicists, and has elucidated how diagrams and displays function in supporting effective reasoning. These observations have been part of the research base used to develop an introductory physics course that raised students' scores on comparable final exams from averages in the 60's to averages in the 80's. For six years Professor Larkin directed the McDonnell Foundation's Program in Cognitive Studies for Educational Practice. During this time a number of cognitive scientists, using results from cognitive science, produced new learning results in a variety of pre-college classrooms.*

Appendix

To be published as a "guest comment" in the American Journal of Physics.

Standards and Measurements in Physics: Why not in Physics Education?

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Standards and measurements have played a centrally important role in the development of physics. They have yielded reliable data based on accurate and reproducible observations. They have facilitated meaningful sharing of results among different scientists. They have allowed unambiguous checks of theoretical ideas and have thus led to cumulative improvements of valuable knowledge. For these reasons physicists have, throughout history, expended considerable efforts on refining their standards and measurement methods.

The situation has been quite different in physics education, although the needs are no less. There, a lack of reliable standards and measurements has made it difficult to assess the efficacy of different instructional approaches. Although it is easy to *proclaim* the virtues of various innovative curricula or teaching methods, how do we really know in what respects one teaching method is more effective than another? Or how do we know whether a teaching method, seemingly effective in helping students acquire some abilities, does not fail in helping them acquire other abilities that are even more essential?

Can we expect to achieve much progress in physics education (both in understanding of the basic issues and in practical efficacy) if we lack at least reasonably reliable common measurement standards? Could we not perhaps develop and use better standards? The following comments explore these questions in the hope of stimulating more serious consideration of them.

Formulating basic standards

Scientists, concerned with accurate measurements, who sometimes officially meet to arrive at a consensus reflecting their best judgments, establish standards in physics. Standards in physics education would similarly need to be formulated by a careful process leading to a consensus among knowledgeable workers in the field.

Better standards might perhaps most usefully be developed for the introductory college-level physics course for physical science or engineering students. Not only is this an important course faced by many instructors and students. Physicists would probably also find it easier to agree about the aims of this course than about courses intended for biology majors or non-scientists.

The first need would be to agree about *what* the standards should specify. The aim of any instruction is designed to endow students with new capabilities enabling them to cope better with later courses, jobs, or other tasks in their lives. Mere specification of a syllabus, listing the topics to be "covered" in a course, does not indicate what students actually learn. Accordingly, educational standards need to be *performance standards* specifying what students should actually be able to *do* after completing a course.

One should, at least, be able to agree on some *minimal performance standards.* e.g., on a half dozen or so kinds of *basic* capabilities expected of all students emerging from a one-semester course. One might perhaps hope that students learn more than that. But any course in which students fail to acquire these basic capabilities could then be clearly judged a failure.

The mere discussion of basic standards would force physicists to examine more closely their teaching goals and to specify the actual capabilities expected of their students. I am sure that there would be heated debate reflecting diverse points of view and previously unexamined assumptions. But the debate would be very healthy in confronting issues that are often not explicitly addressed. For example, should students rely on various memorized formulas or be able to reason from a few basic principles? Should they be able to solve problems mathematically or should they also be able to do qualitative reasoning? Should they mostly engage in numerical manipulations or also be able to obtain algebraic results that they can examine for their qualitative implications? Should they just be able to obtain answers or also be able to articulate well-based scientific explanations?

Operational specification of standards

Operationally meaningful standards need to be accompanied by procedures specifying *how* they can be determined by actual measurements. Some detailed work would, therefore, need to be done to design questions or tasks exemplifying the basic capabilities specified by these standards. There would also need to be agreement that a student's ability to answer such a question, or to perform such a task, would provide good evidence that he or she possesses the specified capability.

The Hestenes tests[11] provide good examples of questions designed to assess one basic kind of capability desired of students in an introductory physics course. However, other basic capabilities important in such a course would also need to be specified (e.g., the ability to apply Newton's laws to solve simple mechanics problems).

Utility for assessments. Suppose that consensus had been reached on a few basic performance standards in a course and that each were accompanied by a set of N questions designed to assess achievement of the specified performance. These N questions (where N might be about 30) should be approximately equivalent and could have been empirically tested to ensure that they are of comparable difficulty.

One could then construct an assessment instrument (e.g., a final examination) by selecting at random one question for each of the specified kinds of performance. No one, including the instructor teaching the course would know beforehand, which of these questions would be selected. Hence one would eliminate the dangers of bias, e.g., of deliberate or inadvertent teaching directed at particular questions on the test. (If the number N of possible questions is large enough, trying to teach students to answer *all* of them would pretty much ensure that students have attained the desired competence.)

Persons interested in assessing instructional effectiveness would then have available measuring instruments allowing them to determine more reliably in what ways a teaching method used one

[1] Halloun, I.A. and D. Hestenes, 1985. The initial knowledge state of college students. *American Journal of Physics*. 53:1043-1055. Hestenes, D. and M. Wells, 1992. “A mechanics baseline test.” *The Physics Teacher*. 30:159-166. Hestenes, D., Wells, M. and G. Swackhamer, 1992. “Force concept inventory,” *The Physics Teacher*. 30:141-158.

year is more effective than another one used previously – or more effective than another method used by others willing to use the same measurement methods[2].

Purely individual efforts might help to achieve some of these aims, but would suffer from some insurmountable limitations. In particular, there would then be no assurance that measurements made by one individual would be deemed legitimate or significant by others. Even more important, there would be no meaningful ways to compare the efficacy of instructional interventions devised by different people. Good standards and measurements in the domain of physics education, as well as in physics, necessarily require the collaborative efforts of the community of workers in the field.

Practical realizability

The preceding proposals are not beyond the bounds of realistic feasibility, especially if the following points are kept in mind: 1) These proposals aim to improve the present situation in physics education, but do *not* pretend to achieve perfect standards. However, even modest improvements could be quite valuable; 2) Standards are not to be cast in stone, but can be periodically reexamined and modified. (Even in physics standards get periodically refined or even redefined.); and 3) There is no compulsion forcing anybody to abide by any formulated standards. However, such standards could be used to good advantage by people interested in more reliable assessments of instructional effectiveness. Furthermore, the very existence of these standards could beneficially influence teaching practices.

Well-specified performance criteria in any field help to avoid fruitless debates and wasted efforts. When the goals are clear, it becomes much easier to decide the merits of alternative approaches and to ensure cumulative progress. It will probably always be more difficult to specify standards and measurements in physics education than in physics, but it seems possible to do significantly better than is currently the case.

[2] Some statistical sampling issues would need to be addressed in these measurement procedures, but they would be less severe than those prevalent at present.

Contributions of Cognitive Science to Undergraduate Education

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Cognitive science is an interdisciplinary endeavor involving cognitive and cognitive developmental psychology, computer science, and the neurosciences. The aim of cognitive science is to understand the workings of the mind/brain. Hence, its insights are basic to the development of an understanding of human mastery of mathematical and scientific material and habits of thought. An emerging subdiscipline within cognitive science aims explicitly to develop knowledge relevant to learning and instruction. (For a readable and eloquent summary of this movement, see John Bruer's 1993 *Schools for Thought*). This emerging sub-discipline can be seen as reinventing, or at least reshaping, traditional educational psychology.

Educationally oriented cognitive scientists have worked on several problems whose solution is necessary to effective teaching of mathematics and science. In this short paper, to give participants in the Social Sciences Workshop a sense of the potential for cognitive scientists to contribute to the improvement of undergraduate education, I discuss two problems which cross cut various mathematical and scientific fields, and two developments with specific relevance to the teaching of certain fields (physics and geometry). Thus, this paper is mainly addressed to answering the first question posed to the Workshop ("*What are the implications of cognitive research for an understanding of how students learn?*"), although I also touch on issues of promoting flexibility and life-long learning (question 6), issues of diversity (question 5) and what is needed in terms of a research agenda (question 8).

Transfer of learning from one context to another

One issue basic to effective education is devising conditions under which students will show *transfer*, or generalization of learning. That is, having 1earned a skill in one context (e.g., mathematical operations of compounding in the context of calculating compound interest), we want people to be able to apply this knowledge in a different context (e.g., velocity problems). Transfer of skills and knowledge from domain to domain will likely be increasingly important, as we move into an era in which workers will need to adapt flexibly to changing technology and to different work situations. Unfortunately, the cognitive literature shows that people are frequently distressingly narrow and rigid in their transfer, realizing the applicability of existing knowledge and skills only when its relevance is explicitly pointed out to them.

At the same time, there are beginning to be demonstrations that this narrowness and rigidity can be overcome. Teaching needs to be aimed at producing *decontextualization*, while at the same time not itself being decontextualized. That is, people learn best when they study a problem in context, motivated by interaction with physical materials and relevance to real-world problems. But they also need to encounter multiple instantiations of underlying principles, each in context, but with the deeper similarities a focus of instruction. For example, students appear to learn compounding in a more generalizable fashion in mathematics classes, in which they encounter a variety of problem types, than in finance or in physics classes, in which the domain of application is narrower. Teaching based on the principles of contextualized instruction with a range of domains of application can help students learn general principles and procedures, whose relevance to new situations they can see spontaneously.

This newly achieved understanding of the nature of the instruction, which is necessary to result in transfer, and generalization presents a research opportunity to NSF. Cognitive scientists can build on their understanding of when transfer is and is not achieved to work in partnership with instructors of specific mathematical and scientific disciplines to devise curricula which will maximize deeper understanding (and hence transfer) of an identified number of basic principles. Facilitating interdisciplinary research partnerships involving the mathematical and scientific disciplines with cognitive sciences should be an important priority for NSF.

Student diversity as related to patterns of cognitive ability and learning styles

As we all know, undergraduate student bodies are increasingly diverse in cultural background, age, and level of academic preparation. This fact is sometimes interpreted as implying that instructional styles need to be correspondingly diversified, to accommodate the different patterns of intellectual strengths and weaknesses seen in different groups and to accommodate what is conceptualized as different learning styles shown by different groups. However, while appealing, research support for these assumptions is largely lacking.

One subtopic in this general realm of discourse concerns *visuospatial ability*, generally agreed to be one of the two most important components of general intelligence, the other being verbal intelligence. Certain types of visuospatial ability show fairly sizable sex differences. There are recurring attempts to link this fact to sex differences in mathematical achievement and to recommend that different instructional strategies be used with males and females because of this difference. However, such recommendations are shortsighted. There is compelling evidence that visuospatial ability is underdeveloped in both men and women and extremely responsive to training and instruction (see review by Baerminger and Newcombe, 1995). There is a need for research on the benefits of linking interventions designed to maximize the spatial potential of undergraduates to facilitating their mathematical and scientific learning.

Second, diversity is frequently conceptualized in terms of hypothesized differences in learning styles across populations. However, the cognitive literature is not encouraging of this conceptualization. To be useful, learning styles would need to be operationally definable, reliably assessed, show long-term stability, and, most importantly, be related to instructional style so that particular types of instruction could be paired with particular students. The search for such *aptitude-treatment interactions* has been an active one, but few have been found.

There is a possibly interesting exception to this rule, however, in recent work by Robert Sternberg at Yale University. Sternberg has reported reliable and valid assessment of analytic, creative and practical intelligence, coupled with maximization of learning in an introductory psychology course when instructional styles are matched to student learning styles. Following up on this finding in teaching mathematical and scientific content represents another example of a research opportunity for NSF in efforts to pair cognitive scientists with instructors m mathematical and scientific subjects.

Changing student misconceptions about physics

Cognitive scientists have documented that students, even at the college level, frequently have intuitive notions of physics which are fundamentally different from physics the way physicists think of it. College students may predict that balls shot out of curved tubes will follow curved paths of motion after release, or think that a heavier object dropped from a tower will hit the ground before a lighter one dropped at the same time from the same height. Such misconceptions may appear discouraging to instructors. Or, instructors may simply attempt to contradict these beliefs, lecturing on the "correct" way of thinking about these problems. Unfortunately, traditional teaching techniques are frequently ineffective. For instance, students are prone to predict a curved path for the ball shot from a curved tube even after taking a college course covering mechanics.

Curricula, which take misconceptions as a point of departure rather than a roadblock, can be more successful. A program developed for a high school physics course by Jim Minstrell, in collaboration with Earl Hunt, a cognitive scientist at the University of Washington, is frequently cited as an example. The Minstrell approach takes students' thinking about physical phenomena as a point of departure, working to arrange experiences in which students realize how different aspects (or facets) of their thinking are incompatible, and then work to resolve these impasses. Teaching through impasse resolution is slow, but effective. Impasse resolution approaches could easily serve as the basis for college curricula as well. The research challenge for NSF is again to commission interdisciplinary groups of cognitive scientists and mathematicians/scientists to work together on curricular developments suggested by cognitive science.

A technology-based program of geometry instruction

Students frequently dislike geometry, and relatively few master the skill of constructing geometric proofs. John Anderson, a cognitive scientist at Carnegie-Mellon University, has devised an interactive computer program, which can impressively increase high school students' ability to do proofs. The approach taken in building the program is one that does not necessarily depend on technology. Teachers also could learn to teach using the ideas, which the program uses, such as those experts frequently approach proofs by trying both to reason forward from the givens and backward from the desired conclusion. Again, the research challenge is implementation.

Conclusion

This short paper was aimed to give workshop participants a sense of the relevance of cognitive science to instruction by presenting four examples. Much has been achieved, but basic research is far from over. For instance, there is still considerable controversy about how one can maximize transfer in problem-solving situations, and several competing models of the process exist (see review by Reeves and Weisberg, 1994).

NSF could contribute to improving undergraduate instruction by supporting cognitive science in two ways. First, funding is needed for basic research in cognitive science on topics with educational relevance. While there are, theoretically, existing funding mechanisms within NSF for such research, in actuality the SBER programs such as Human Cognition and Perception frequently look askance at educationally-oriented proposals and the EHR programs may find cognitive-science proposals too theoretical and too far removed from the field. Joint programs would be helpful, in which the announced goal is to fund proposals in the intersection of the two research domains. Second, funding is needed for the research/practice collaborations necessary to effective implementation of the insights and achievements, which already exist. There are many difficult steps between scientific understanding and widespread adoption of specific curricula and practices. Detailed recommendations, along these same lines, are elaborated in a report written on an NSF-sponsored conference on a very similar topic, namely the contributions of cognitive science research to K-12 mathematics and science education (Hawkins and Newcombe, 1994).

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Cognitive Science and Undergraduate Education

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The primary purpose of this paper is to address questions 3 and 6 in the guide to the workshop discussion from the perspective of the cognitive sciences. From this perspective, question 3 asks how introductory undergraduate courses in the cognitive sciences effectively promote scientific and quantitative literacy. Question 6 asks how knowledge of the cognitive sciences prepares students to meet the challenges of the 21st Century. I will also address the research and development efforts (Questions 7 & 8) that are needed to realize the potential of cognitive science as an area of undergraduate science instruction.

Undergraduate education in cognitive science

Cognitive science is the science of intelligence in humans, other animals, and artificial systems. It includes the study of perception, learning, memory, knowledge, meaning, reasoning, language, attention, affect, consciousness, and the control of action. In undergraduate curricula, the field is offered both as a new scientific discipline that emphasizes computational models of cognitive processes and as an integrative interdisciplinary field that draws together insights from several traditional disciplines, including psychology, biology, computer science, linguistics, philosophy, and anthropology. In the context of the present workshop, it should be pointed out that cognitive science highlights the somewhat arbitrary nature of traditional distinctions between physical, biological, and social sciences. Cognitive science has significant social, behavioral, biological, and even physical (e.g., psychophysical studies of sensory systems) dimensions. Stillings (1995) is a recent report on the current status of undergraduate education in cognitive science. Stillings et al. (l995) is a survey of the field.

Scientific literacy and the social sciences

Before answering Question 3 for the cognitive sciences, the larger context of the question should be considered. We should not assume that the typical undergraduate science distribution requirement could effectively promote scientific literacy, if only the mix of physical, biological, and social sciences were optimal. Undergraduates may not be taking enough science, and the science that they take may not be taught effectively. Empirical research, of the kind described by other participants in this discussion, is required to assess the effectiveness of and to improve college-level science instruction.

We should also not assume that instruction in the physical and biological sciences alone provides, or is even capable of providing, a superior or sufficient path to scientific literacy. For the foreseeable future, many policy issues that will concern a scientifically literate citizenry fall at least partly in the domain of the social and behavioral sciences. Furthermore, as I will suggest below, the social and behavioral sciences are equal, and in some cases superior, to the physical and biological sciences as arenas for general science education.

How courses in the cognitive sciences can promote scientific and quantitative literacy

The contributions of courses in the cognitive sciences to science education fall into five areas. First, cognitive science provides a scientific approach to a distinctive set of questions that is of great interest to contemporary undergraduates: What is the nature of meaning? What distinguishes perception from knowledge objective? What is the relationship between mind and brain? What is consciousness? Cognitive science's empirical approach to such questions can bring science to a new group of undergraduates, and it can show them the connections between science and areas of life and academic pursuit that can seem distant from science. Cognitive science can also play a crucial role in helping students to critically understand mind-brain-behavior relationships in an era of rapidly expanding knowledge in neuroscience and behavior genetics, as well as in cognitive science.

Second, cognitive science is a superb field for giving beginning and intermediate undergraduate students hands-on experience with science. Instrumentation costs, even for sophisticated original research, are generally low, and many currently active research questions are accessible to undergraduates. Often, a personal computer can serve as the student's laboratory. A wide range of cognitive psychological experiments on perception, memory, language, thinking, and motor control can be run and analyzed on unmodified desktop computers. Students can both replicate experiments and work with high-level software that allows them to design and run original experiments. Artificial intelligence and cognitive simulation software that is powerful, flexible enough to support original research, and usable by undergraduates can also be run on personal computers (e.g., Anderson, 1993; McClelland and Rumelhart, 1986).

Third, students can study reasoning, critical thinking and the scientific method in a context where normative conceptions of rationality are compared with empirical research on human thought. This naturalistic approach to epistemology allows the student to see the motivation for normative conceptions and to learn to recognize situations in which biases and heuristics in everyday thinking lead to sub-optimal conclusions. Recent research suggests that it is possible to train people to apply abstract rules of reasoning more successfully in varying real situations (Nisbett, l993), and this research is finding its way into curricular materials on critical thinking (e.g., Halpern, 1995a, 1995b). A more naturalistic epistemology can also provide a realistic appreciation of the special strengths of scientific reasoning to students who have lost, or perhaps never possessed, an uncritical faith in science (Giere, 1988; Thagard, 1988).

Fourth, cognitive science is an excellent field for attracting students into an encounter with formal mathematical intellectual disciplines. Within the context of attractive questions about the mind and brain, the student can encounter such disciplines as experimental design and statistics, probability and decision theory, formal logic, the theory of algorithms, and the theory of dynamical systems. Students who become fascinated with artificial neural networks as freshmen, for example, discover that they must take calculus and linear algebra to pursue their interest further.

Finally, cognitive science is being applied in important areas of public policy and technology. Cognitive scientists are pursuing issues in human-computer interaction, workplace organization, reading remediation, mathematics education, cognition and aging, and the reliability of traumatic memories, among many others. Increasingly, some familiarity with cognitive science will be a condition for informed citizenship.

Not all courses in the cognitive sciences have all of the characteristics mentioned. The range of courses that possess at least some of them is fairly broad, including courses in cognitive science, courses in constituent disciplines of cognitive science such as psychology or psycholinguistics, courses in overlapping disciplines such as psychology or neuroscience, or special interdisciplinary topics courses such as critical thinking.

Considerable faculty development and research on and development of instructional approaches and materials are also needed to fully realize the potential just sketched.

How knowledge of the cognitive sciences helps prepare students to meet the challenges of the 21st Century

The characteristics of the cognitive sciences discussed above are equally relevant here. The cognitive sciences can engage students in science. They are a context for learning critical thinking and formal quantitative and scientific methods. They are critical to the understanding of many emerging public policy issues.

Students who major or minor in cognitive science tend to have a broad intellectual base and strong analytical and writing skills. Many of them, of course, go on to graduate work in the cognitive sciences, computer science, neuroscience, medicine, or education. There are also anecdotal reports from faculty members involved in cognitive science programs that their students are successful in the job market upon graduation. They have skills in computer programming, research design, data analysis, and writing, and they have knowledge of human cognition that is of value in the rapidly growing information-intensive sectors of the economy.

Research and development in cognitive science instruction

The potential for undergraduate instruction in the cognitive sciences has not been fully realized. The improvement of undergraduate programs in cognitive science and their curricula for majors are addressed in Stillings (1995).

The potential of the cognitive sciences to contribute to scientific and quantitative literacy in non-science majors would be enhanced by targeted support for the development of new instructional approaches and materials. The analysis above suggests three particularly promising areas for funding.

The first area is the development of critical thinking courses that blend the cognitive psychology of reasoning and decision making with training in normatively correct reasoning that is based on recent research in transfer of training and skill decontextualization (see Nora Newcombe's contribution to this workshop). Such courses might blend material in deduction, causal reasoning, experimental design, probability theory (particularly reasoning with conditional probability and Bayes's theorem), and topics in elementary statistical inference, such as the law of large numbers and statistical regression.

The second area is the development of introductory courses that give students significant hands-on experience with cognitive science research, either by running original experiments or by performing original simulations.

The final area is the development of courses that explore public policy issues that have significant cognitive science content. Such courses could be taught in a way that focused on the learning of transferable critical thinking skills as well as on a particular content area. Such courses also offer many avenues for collaboration between the cognitive sciences and other disciplines. For example, a cognitive scientist, an economist, and a philosopher could jointly develop a course on cost-benefit and risk-benefit analysis.

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